Tracking and Visualizing the Evolution of the Universe: In Situ Parallel Dark Matter Halo Merger Trees

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1. What are Dark Matter Halos?

- Dark matter constitutes nearly 83% of the matter in the universe, much of it is in the form of localized clumps called halos.
- Atomic matter falls into the clumps where stars and galaxies form. Mergers of halos lead to formations of galaxy groups and clusters.
- Dark matter neither emits nor absorbs electromagnetic radiation and thus cannot be directly seen by telescopes.
- Can be detected by observing its gravitational effects on stars and galaxies and gravitational lensing of background galaxies.
- Essential to study dark matter evolution by observing the sky and then building theories to understand the underlying physics.

2. Contribution

- Track halos and satellite halos at each time step, in parallel and in situ with a cosmological N-body simulation.
- Detect and classify events such as birth, death, merger, split and continuation for satellite halos and host halos to understand their behavior.
- Store the tracking results, event detection and changes in halo properties in halo merger trees.
- Visualize the merger trees in an open-source visualization application, ParaView.

3. Framework

- In Situ Setup

3.1. Hardware/Hybrid Accelerated Cosmology Code (HACC) with Dynamic Parallel I/O (DIY Data partitioning, Data exchange, Parallel I/O)

3.2. Halo Tracking and Merger Tree Process

4. Possible Halo Interactions

Dark matter halo substructure is dominated by satellite halos. Gravitational forces exerted by halos and satellite halos can give rise to the following interactions:

- Two or more Halos can merge into a bigger halo.
- Two or more satellite halos within a host halo can merge into a single satellite halo.

5. MergerTree Visualization

Example Merger Tree for Halo 122

- The N-body simulation runs over 500 time steps, but halo information is stored for 40 intermediate time steps.
- Each sphere represents a halo. Since halo density varies over a wide range, we use a logarithmic scale for sphere size.
- Redshift axis represents the evolution period (timesteps). Lower redshift corresponds to younger halos.

- The series of spheres represents the evolution of halo H_{245}.
- Halo H_{245} merges with halo H_{122} at redshift 1.

- Various mergers taking place in the evolution of halo H_{245}.

- The main halo being analyzed, halo H_{122}.

- Evolution of Halo 122 with velocity vector

- Arrows attached to the spheres show direction of halo movement. White lines joining spheres from top are edges depicting mergers.
- Every merger causes a change in direction of movement of halo H_{122}.